The Diverse Population of ULIRGs ⋆

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We present results from an on-going Hubble Space Telescope (HST) survey of a large sample of ULIRGs (Ultra-Luminous IR Galaxies). New ground-based observations are now being used to complement the HST data and to assist in the interpretation of these complex objects. A rich spectroscopic, morphological, and dynamical diversity is found within the ULIRG population, nearly 100% of which are merger and/or collision remnants. The consequences of this diversity may apply to the interpretation of distant submm/FIR sources and their subsequent evolution.

Key words: interacting galaxies, infrared galaxies, starbursts, mergers

1 Collisions, Mergers, Starbursts, and ULIRGs

It has been known since the pioneering work of Larson & Tinsley [14] that collisionally disturbed galaxies (e.g.,[1]) have abnormally high star formation rates compared to isolated galaxies of similar type. It was not until IRAS discovered the population of luminous IR galaxies (LIRGs) and ultraluminous IR galaxies (ULIRGs), having extremely high star formation rates (100–1000× the Galactic star formation rate), that the links between strong star formation, high IR luminosity, and galaxy-galaxy encounters were made inseparable [13]. The observation that some galaxies have higher rates of star formation than can be sustained by their current gas content over a full Hubble time led

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to the idea of ”starbursting” galaxies [17]. It has thus been unequivocally established that the LIRG, ULIRG, starburst, and collision+merger processes are physically related phenomena that are intimately connected to the star formation history of galaxies, galaxy formation, and galaxy evolution (for a review, see [15]). In fact, most recently, it has been estimated that a significant portion of the cosmic IR background is produced by cosmologically distant LIRGs and ULIRGs (i.e., dusty starbursts; [3], [4], [16]).

2 The Rich Diversity within the ULIRG Population

We have been studying a large sample of ULIRGs with both HST imaging and ground-based spectroscopy ([2], [5], [6], [7], [8], [9], [10], [11], [12]). Among the plethora of results being derived from this rich survey database, we have found strong evidence for a multiple-merger origin for many of the ULIRGs in our sample [10]. We have established a morphological classification scheme for ULIRGs that indicates that the sample is nearly equally divided between single objects (e.g., merged; disturbed; or IR-luminous QSOs) and multiple objects (e.g., pairs; compact groupings; or strongly interacting multiples). We find very little luminosity variation across these morphological classes [8]. We have also verified the long-known belief that the ULIRG population has a high interaction rate. From a sample of nearly 130 ULIRGs, we find $\sim$98% show evidence for close neighbors, tidal disturbances, or on-going merging. In several cases, the galaxies were previously classified as isolated and/or undisturbed from low-resolution ground-based imaging. Our sample is the largest that has been used to derive this interaction rate estimate. Most recently, we have been obtaining multi-fiber integral spectroscopy for several ULIRGs, which indicate that luminous gas-rich knots are ubiquitous among these galaxies. In every case, we find multiple line emission sources, frequently in regions detached from the cores of the galaxies or from any other region that is luminous in continuum light. These line-emitting regions have spectral characteristics of H II regions, LINERS, or AGN. In some cases, these line-emitting clouds may be simply reflecting the emission from a dust-obscured nuclear source. In the case of Mrk 273, we find a LINER nucleus and an extended off-nucleus Seyfert 2 nebula [11]. In the case of IRAS 12112+0305, we find that the observed ionized gas distribution is decoupled from the stellar main body of the galaxy, with the dominant continuum and emission-line regions separated by projected distances of up to 7.5 kpc. The two optical nuclei are detected as faint emission-line regions, and their optical properties are consistent with being dust-enshrouded weak [O I] LINERs [12]. In the case of IRAS 08572+3915, we find no evidence for a LINER or Seyfert-like nucleus in either of the galaxies, contrary to previous claims. This is unusual for a *warm* ULIRG such as 08572+3915. Tidal-induced star-forming knots, $\sim$7 kpc from the nuclei and along the tidal tails, are traced by the presence of bright [O III] emission [2].

In summary, we find that the ULIRG population of galaxies has a rich dynamical diversity, demonstrated both morphologically and spectroscopically. This points to a rich evolutionary history for these objects, with strong connections between their hierarchical mass assembly history, dust and gas evolution, star formation episodes, metal enrichment, and nuclear activity. The consequences of these connections are found in the spectral energy distributions both of these galaxies and of their high-redshift counterparts, and thus our interpretations of these connections for nearby galaxies may thus also be applicable to the interpretation of distant submm/FIR sources now being discovered and soon to be discovered in the new long-wavelength ultra-sensitive galaxy surveys.

References

[1] Arp, H. C. 1966, ApJS, 14, 1

[2] Arribas, S., Colina, L., & Borne, K. D. 2000, ApJ, 545, 000 (in press)

[3] Barger, A. J., Cowie, L. L., & Sanders, D. B. 1999, ApJ, 518, L5

[4] Blain, A. W. et al. 1999, ApJ, 512, L87

[5] Borne, K.D., et al. 1997a, in "Star Formation, Near and Far", eds. S. Holt & L. Mundy (Woodbury: AIP), 295

[6] Borne, K.D., et al. 1997b, in "Extragalactic Astronomy in the Infrared", eds. G. A. Mamon, T. X. Thuan, & J. Tran Thanh Van (Paris: Editions Frontieres), 277

[7] Borne, K.D., et al. 1998, in "After the Dark Ages: When Galaxies Were Young", eds. S. Holt & E. Smith (Woodbury: AIP), 220

[8] Borne, K. D., et al. 1999a, Ap&SS, 266, 137

[9] Borne, K. D., Colina, L., Bushouse, H., & Lucas, R. A. 1999b, ApJ, 527, 554

[10] Borne, K. D., Bushouse, H., Colina, L., & Lucas, R. A. 2000, ApJ, 529, L77

[11] Colina, L., Arribas, S., & Borne, K. D. 1999, ApJ, 527, L13

[12] Colina, L., Arribas, S., Borne, K. D., & Monreal, A. 2000, ApJ, 533, L9

[13] Joseph, R., & Wright, G. 1985, MNRAS, 214, 87

[14] Larson, R. B., & Tinsley, B. M. 1978, ApJ, 219, 46

[15] Sanders, D. B., & Mirabel, I. F. 1996, ARA&A, 34, 749

[16] Smail, I. et al. 1998, ApJ, 507, L21

[17] Weedman, D. et al. 1981, ApJ, 248, 105